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Operational Research on Design and Process Optimization of Ozone Water Application in Kitchen

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Abstract. Food safety is a very important focus in the kitchen industry today, as bacteria such as E.Coli and Salmonella are very difficult to tackle. The objective of the present study was to optimize nozzle designs that use ozone technology to bring out the best results in cleaning and sterilizing the kitchen utensils in Taylor's University School of Hospitality kitchen area. This includes customization of the Medklinn International Sdn Bhd ozone machine and nozzle profiles that improve the effectiveness of ozone generated. Reduction or elimination of chemicals and water usage would be a part of the study. This will bring a huge impact on cost effectiveness, time saving and safety of the users. Return on investment (ROI) using ozone technology is calculated at the end of the research. To compare between the traditional way of cleaning and using ozone technology, the volume of water and dishwashing liquid used, and the Relative Light Units (RLU) before and after washing were recorded. The RLU numbers are found using the 3M Clean Trace measuring equipment. RLU was recorded to determine the cleanliness of the kitchen utensils before and after washing. It has been proved that ozone water with the accompaniment of the selected nozzle prototype is as efficient as the traditional way of cleaning.

1 Introduction

The cleanliness of kitchen area, utensils and stoves is essential in the food processing industry. Diarrhea is a concerning issue for travelers as 1 out of 3 people will be affected in this health issue. Hikers and people who go on adventure trips are very prone to this problem[1]. In 2015, World Health Organization (WHO) has estimated that 1 in 10 people are prone to foodborne diseases which also killed 420,000 people[2]. It was also reported that Africa and South East Asia are the two regions that are in the high risk zone[2]. There were 125,000 of children under five years old are killed due to illness from foodborne diseases every year [2]. It was found out that 16% of the foodborne diseases outbreaks from England and Wales are linked with the food preparation in the house [3, 4].

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Cross contamination is one of the reason to the foodborne disease and it caused 28 out of 101 outbreaks to happen [3]. Cross contamination can happen either by hand to the plates, from the plates to the food, the utensils to the food, or even in the washing process with the usage of sponge and water [3, 5, 6, 7]. In order to reduce and eliminate this issue, different washing up systems have been created. Researchers believe that rather than tackling the cleanliness of water, the cleanliness of kitchen utensils and hand hygiene are two very important factors to prevent foodborne diseases[1, 8]. Cross contaminations on food happens very often in the process of cutting, trimming, rinsing and washing [8]. Bacteria infect almost all the kitchen area, as study shown in appendix 1 and 2, swap tests were taken in a hospital kitchen to show the amount of infected areas. These results were also picked up from pre-processing zones for food, storage area and cooking area.

Biofilm is the form of 99% of bacteria in the kitchen. Biofilm formation makes the bacteria to be able to live in either biotic or abiotic surfaces. Therefore, another study on bacteria infecting kitchen surfaces is done as well [9]. Table 1 shows the total colony forming unit count on a cafeteria kitchen. It can be seen that the bacteria count is quite alarming even in dishwashers, sink, countertop areas, food waste container and pots. These are some areas that show that even bacteria would live in cleaning environment and cooking pots which would promote cross contamination. This also shows that the existing steps of cleaning could not disinfect microorganisms efficiently, and potential biofilm formation is not effectively prevented as well [9].

Table 1. Total colony forming unit (CFU) count on a cafeteria kitchen [9]

Surface No.	Surface Area	Total Aerobic Count (log CFU/100cm ²)	Bacteria
1	Cold Room	5.90	Brachybacterium, Brevundimonas, Kocuria, Pantoea, Paracoccus, Roseomonas, Sphingobacterium
2	Pretreatment Countertops	3.83	Bacillus, Curtobacterium, Gordonia, Kocuria, Pantoea, Pseudomonas, Sphingomonas, Staphylococcus
3	Sink	4.14	Bacillus, Enterobacter, Raoultella
4	Faucet in the sink	5.35	Bacillus, Enhydrobacter, Escherichia, Kocuria
5	Roasting/frying countertop	3.63	Bacillus, Kocuria, Lysinibacillus
6	Spice rack	4.84	Bacillus, Microbacterium, Pantoea
7	Soup pot	3.59	Acinetobacter, Bacillus
8	Frying pot	2.16	Bacillus
9	Countertop for completed menu	3.16	Acidovorax, Acinetobacter, Bacillus, Chryseobacterium, Deinococcus, Enterobacter, Sphingomonas
10	Rice cooker	2.73	Acinetobacter, Bacillus, Chryseobacterium, Kocuria, Sphingomonas

11	Food waste container	3.21	Bacillus, Staphylococcus
12	Dishwasher	2.53	Bacillus
13	Sink for dishwashing	2.86	Bacillus
14	Stainless steel trays	1.60	Bacillus
15	Plastic wicker tray	4.07	Acinetobacter, Chryseobacterium, Dermacoccus, Exiguobacterium, Kocuria, Pantoea
16	Iron roasting pan	2.00	Acinetobacter, Kocuria
17	Knives	2.00	Acinetobacter, Bacillus
18	Cutting board (Completed Menu)	2.45	Arthrobacter, Bacillus, Curtobacterium, Kocuria, Microbacterium, Staphylococcus
19	Cutting board (vegetables)	2.97	Acinetobacter, Dermacoccus, Enterobacter, Kocuria, Leclercia, Methylobacterium, Roseomonas
20	Gloves	3.97	Acinetobacter, Bacillus, Kocuria
21	Apron	6.85	Bacillus, Kocura, Pseudoxanthomonas, Rhizobium
22	Fan	4.15	Bacillus
23	Floor	4.65	Achromobacter, Aeromonas, Bacillus, Cellulosimicrobium, Chryseobacterium, Cloacibacterium, Diaphorobacter, Kocuria, Pseudomonas

Hence, in order to prevent cross contamination that will lead to foodborne diseases, studies have been done to optimize the cleaning processes in the kitchen and also trying out with different disinfectants and cleaning agents. Sterilizing of kitchen surfaces using a variety of disinfectants is one of the ways to minimize microorganisms living on surfaces and also preventing cross contamination. In this case, Taylor’s Hospitality and Culinary Arts School (TCHT) is used as the model of research to find out how chemical and disinfectant washing can help in the cleaning of kitchen utensils. A table (Table 2) shows the volume of water and detergent needed to clean 6 kitchen utensils and 2 kitchen stoves.

Table 2. Volume of water used to clean 6 kitchen utensils and 2 kitchen stoves

Items washed	Amount of dishwashing liquid used, ml	Amount of water used for cleaning, L
6 Kitchen utensils	30	143.7
2 Kitchen stoves	15	5.9L

TCHT has been searching for a way to reduce the cost of cleaning and also reducing the steps to do the cleaning so that cleaning of the kitchen would be faster and requires less man power. There are a few ways to optimize the current cleaning method to achieve TCHT’s objective:

1. In order to reduce chemical usage, TCHT has the possibility to use higher concentration of dishwashing liquid so that less chemical will be used to dilute in water but producing the same effect. However, more concentrated dishwashing liquid will also be higher cost.
2. In order to achieve less man power, the steps of cleaning have to be reduced. An alternative which can bypass the use of degreasing and too much scrubbing can reduce man power. In this case, the alternative way has to be good in sterilizing, degreasing and cleaning off dirt in one shot. Hence, reducing cleaning steps.

Cleaning using ozone technology is one way that can reduce the use of chemicals as ozone is well known to be a good disinfectant because of its highly reactive properties[10, 11]. Ozone is also proven by many ozone technology companies to be a good degreaser. Hence, ozone is widely used in the western part of the world in industry cleaning, sterilizing and degreasing. However, ozone is not as well known in this tropical region as in the western world. Ozone technology is not unknown in kitchen area as ozone is also used in cleaning vegetables and fruits before cooking. One of the examples is in the cleaning of spinach [12].

Hence, this research is to introduce the usage of ozone technology in order to enhance and improve the ways to clean the kitchen utensils which takes up most of the cleaning time in Taylor’s Hospitality and Culinary Arts School. The objective is to customize and develop designs to bring out effective applications of ozone technology in cleaning kitchen utensils. Furthermore, the research is carried out also to prove that the usage of ozone technology reduces the usage of chemicals, man powers and time consumption in cleaning process.

2 Methodology

This research is done by cleaning stainless steel kitchen utensils in Taylor’s Hospitality and Culinary Arts (TCHT). The research done on different methods is shown in Table 3.

Table 3. Methods of testing

With Nozzle	Without Nozzle
Without ozone	Without ozone
With ozone	With ozone

2.1 Calculation of water and chemical usage in cleaning process

A water flow meter shown in Fig. 1 is attached to the outlet of the water pipe where water flows out for kitchen utensil washing. This is to measure the amount of water used during the whole cleaning process. The amount of water used is compared between the cleaning with and without ozone, and with and without nozzles. The volume of water was controlled during the research, not letting it to overrun before and after washing. The water was only let run when needed.



Fig. 1. Water flow meter with readings in m³

A 10 ml syringe shown in Fig. 2 is used to measure the volume of dishwashing liquid used to clean the kitchen utensils. The dishwashing liquid is already diluted with the ratio of 1 L of detergent to 20 L of water. It is tested with the same methods as in Table 2. The detergent is added on by an increment of 1ml onto the dishwashing sponge until the worker feels that it is sufficient to clean the pot. This is done to ease the calculation for the efficiency of ozone water cleaning vs non-ozone water cleaning.



Fig. 2. 10 ml syringe for dishwashing liquid measurement

2.2 Customization of ozone machine

The ozone machine in Fig. 3 is provided by Medklinn International Sdn Bhd. The ozone capacity used was 500mg/hr. Ozone is also produced with the presence of oxygen as stated in the literature review. In this case, a consistent provided of oxygen is needed so that the ozone produced will be consistent as well. Therefore, an oxygen concentrator is used to provide the consistent amount of oxygen. A 1 LPM oxygen concentrator is used for this research. A venturi shown in Fig. 4 is used for suction of ozone gas to be diluted in water is MK584 (¾ inch inlet and outlet size). This will result in a 1.8 particles per million (PPM) (without nozzle) and 1.25 PPM (with nozzle) concentration of ozone.



Fig. 3. Ozone Machine



Fig. 4. MK584 Venturi [13]

2.3 Nozzle profile

A nozzle is used to have a higher water impact in the cleaning process to remove oil and stubborn dirt on the kitchen utensils. The nozzle design has 16 linear 1.50 mm diameter circular holes with a 3 mm linear distance between each hole. Fig. 5 shows the design of the nozzle used to clean the kitchen utensils. The design has the same number of holes compared to the nozzle used in the traditional way of cleaning in Taylors School of Hospitality and Culinary Arts (TCHT). However, the nozzle profile in TCHT is a shower pattern nozzle. A shower pattern nozzle shows a lower impact force compared to the one in linear. This is because most of the water flow is not blocked at the outlet, hence there is lesser force that pushes the water out of the orifices. However, in linear, the water is constrained to exit only at the middle of the outlet. Hence, pressure accumulates in the nozzle and more force is present to push the water out of the orifices.



Fig. 5. Linear Circular Pattern Nozzle

ANSYS Fluent CFD is running on the nozzle profile to identify the velocity profile and also the pressure at the outlet. A multi-zone, mapped mesh type hexa/prism and free mesh type of tetra/pyramid meshing is done [Fig. 6]. Multi-zone, hex dominant is done because the outlets of the nozzles are having circular patterns and multi-zone work best for these conditions. It has a total of 108202 numbers of elements, average skewness 0.36274 and an average orthogonal quality of 0.79.

For the boundary conditions, Reynold’s number is calculated for the flow to see whether the flow is a laminar or turbulent flow across the nozzle. The equation for Reynold’s number is as follow:

$$\text{Reynold's number} = \frac{\rho v D}{\mu} \text{ (Eq. 1)}$$

Where,

ρ : Density of water

v : Velocity of water

μ : Viscosity of water at 28°C

According to [14], viscosity and the density of water at 28°C is 0.8324 mPa.s and 0.9962 g/cm³ respectively.

$$\text{Reynold's number} = \frac{996.2 \frac{\text{kg}}{\text{m}^3} \times 3 \frac{\text{m}}{\text{s}} \times 0.0092 \text{m}}{0.8324 \times 0.001 \frac{\text{kg}}{\text{ms}}} = 33,031.14$$

The flow is turbulent, Realizable k- ϵ is used as the viscous modelling during all the CFD analysis. The boundary conditions are set to 3 m/s inlet velocity with. This is due to the volumetric flow rate of 12 LPM measured from the pipes of the kitchen in Taylor’s School of Hospitality and Culinary Arts.

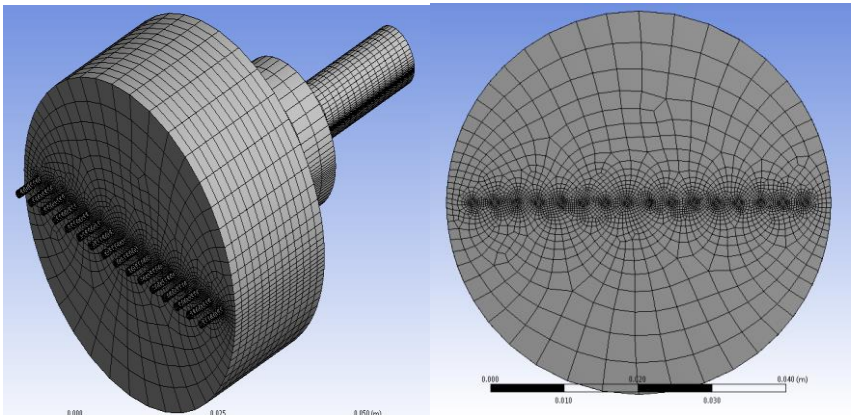


Fig. 6. Multi-zone mesh type

2.4 Cleanliness of kitchen utensil

3M Clean Trace shown in Fig. 7 is used as the equipment to test on the cleanliness of the kitchen utensil. Swabs are taken before and after cleaning of the kitchen utensil using the traditional way (without ozone water) and with ozone water. A cotton bud like stick shown in Fig. 7 are used to swab on the surface (10cm × 10cm) of the kitchen pot before cleaning, and done it again after cleaning. Same applies to with and without nozzle. The measurement is taken as Relative Light Units (RLU). RLU is the measurement of adenosine triphosphate (ATP) present on the kitchen utensil. The higher the RLU, the dirtier the kitchen utensil is. In normal practice, RLU higher than 11 is a caution and higher than 30 is a fail. Hence, RLU lower than 10 is in the safe region [15].



Fig. 7. 3M Clean Trace swab sticks

Kitchen towel and an oil control blotting paper are used to have a qualitative result on the dirt and oil left on the kitchen utensil after cleaning. Results are shown in the next section of discussion.

3 Results and discussion

3.1 Washing of stainless steel pot

Table 4 and 5 show the amount of water and detergent is used for the different methods of washing (as discussed in Table 2). The tables also show the cleanliness (RLU) of the pots before and after washing. Comparing the results with the background reading in Table 2, averagely one utensil needed 23.95 L of water to clean. However, during the research, the volume of water was controlled well hence, there is a big reduction in the volume of water.

Table 4. Cleaning of a stainless steel kitchen pot without nozzle













Variables	Traditional way	Ozone water
Volume of water, L	10.4	11.1
Volume of detergent, ml	4	6
Ozone level, PPM	-	1.8
Pot before washing		
Cleanliness before washing, RLU	674	312
Pot after washing		
Oil and dirt detection after washing		
Cleanliness after washing, RLU (TOTAL REDUCTION OF RLU)	226 (448)	103 (209)
Temperature of water	29.6°C	29.1°C

Table 5. Cleaning of a stainless steel kitchen pot with nozzle

Variables	Traditional way		Ozone water	
Volume of water, L	8		8	
Volume of detergent, ml	5		5	
Ozone level, PPM	-		1.25ppm	
Pot before washing				
Cleanliness before washing, RLU	1106		679	
Pot after washing				
Oil and dirt detection after washing				
Cleanliness after washing, RLU (TOTAL REDUCTION OF RLU)	156 (950)		6 (673)	
Temperature of water	29.5°C		29.1°C	

From Table 4, the RLU reduction for traditional way of cleaning (using just detergent and normal 29.6°C of water) is 66.47% while for ozone water is 67%. Traditional way uses 700ml of water and 2ml of detergent lesser compared to ozone water to achieve the RLU. The difference in water volume and detergent, and also the RLU reduction are not significant in this experiment. Table 5 shows a significant difference in RLU reduction comparing the two methods of cleaning with the same amount of water and detergent used. There was a 85.9% reduction using the traditional way with nozzle and a 99.12% RLU reduction using ozone with nozzle. This has significantly shown that with the use of nozzle in the cleaning process, it increases the RLU reduction by about 20% ~ 30% compared to without the nozzle. Ozone water with the use of nozzle also shown the cleaning process to be very efficient.

The readings are as such because it is due to the properties of nozzle. Although with nozzle, the PPM level is lower than the one without nozzle, however nozzle plays a part in cleaning and also sterilizing. Ozone needs exposure time to the surface in order to kill bacteria, hence when ozone without nozzle is applied, the reduction rate is slower. When nozzle is applied in this case, the nozzle will give impact force to the utensil surface and clearing most of the dirt and bacteria, adding on with ozone, the sterilizing effect is much higher compared to without the nozzle.

So, comparing with nozzle with ozone and without ozone, although both shows more than 80% of RLU reduction, the one without ozone has always show RLU more than 10 which is unsafe to use according to [41]. When comparing without nozzle with ozone and without ozone, both have also failed to the requirement stated in [41]. Hence, ozone and nozzle is the best combination as the RLU reduction for all the cases has shown RLU less than 10, which is safe for consumers. This has proven that even though chemicals are used to wash utensils, it might not be safe for consumption purposes. Ozone has proven to be a strong disinfectant and the utensils that are cleansed by ozone will be definitely safe to use.

3.2 Nozzle and ozone suction in water

The inlet velocity is at 3 m/s and the outlet velocity as the result of the nozzle design is at about 12-14 m/s. Fig. 9 shows the velocity path lines of the flow of water through the nozzle. It can also be seen that there is back flow occurring as it hits the head of the nozzle. The backflow also causes the high pressure of 1×10^5 Pa to be accumulated in the nozzle itself as shown in Fig. 10. As the pressure accumulates in the nozzle, the velocity decreases, the air pressure in the venturi will find it difficult to push the ozone gas to dilute in the water through the venturi. This causes the decrease in ozone suction in the venturi which was from 1.8 PPM to 1.25 PPM (from Table 4 and 5).

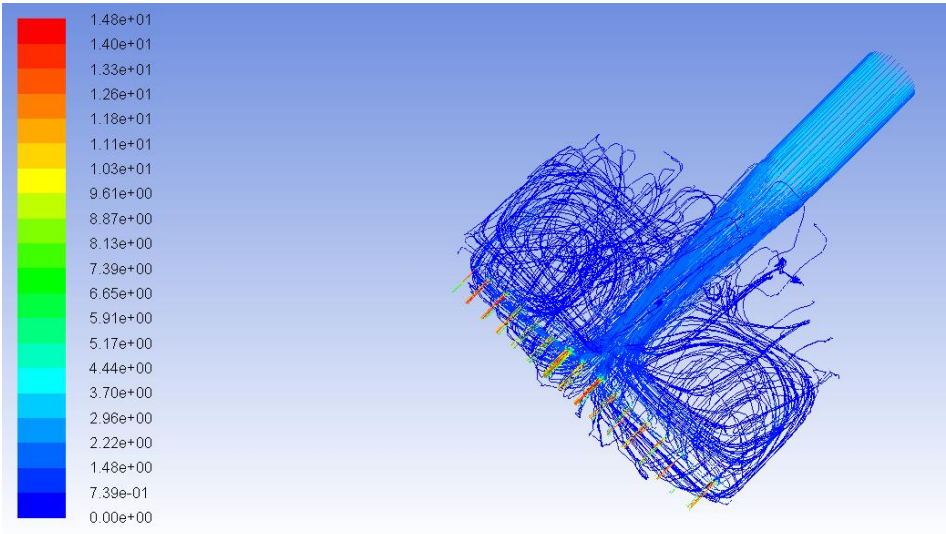


Fig. 9. Velocity path lines

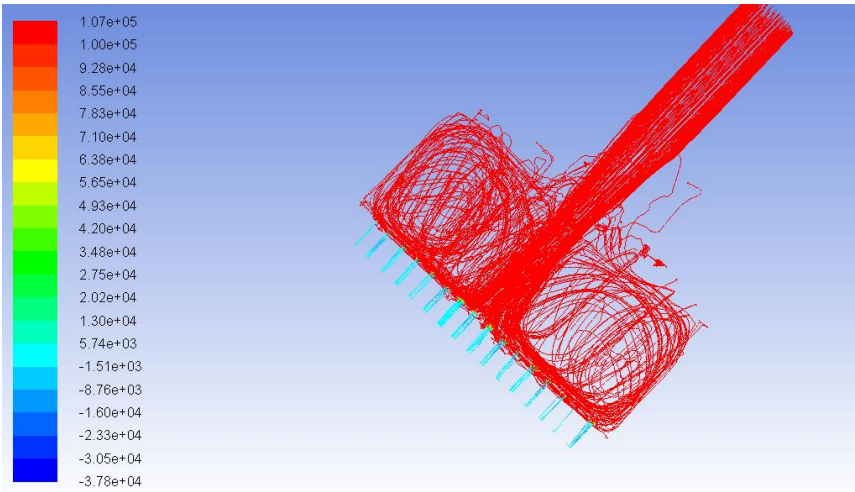


Fig. 10. Pressure path lines

According to [16], the impact force is based on the angle of water distribution from the nozzle. The bigger the angle of water distribution, the lower the impact force. This is because of the kinetic energy losses when it is needed to distribute the water at the big angles. Since the impact force equation is given by,

$$Fs = \frac{1}{2}mv^2 \text{ (Eq. 2)}$$

where the velocity at the outlet will play a part in determining the impact force. When the velocity is higher at the outlet, the impact force will be higher.

The design of the conventional nozzle is based on the nozzle used in TCHT kitchen shown in Appendix 3 and 4. According to literature review [16, 17], a nozzle that produces solid stream has the highest impact force compared to water distributed at an angle. Single hole will give a solid stream flow. However, a solid stream will also lose momentum quicker compared to others, even though all nozzles will lose momentum after the water exits from the orifice [17]. Hence, the distance of nozzle to the surface intended to be washed have to

be nearer so that the water can hit the surface with minimal losses of momentum. A single hole is also not very user friendly to wash kitchen utensil as the focus area is small and usually a kitchen utensil is at sizes of 10 cm – 20 cm. So in order to optimize the washing, a linear pattern is done with 3 mm apart so that the water streams could wash the kitchen utensil at a bigger surface area. It can mimic a fan pattern nozzle but having solid streams as well to increase impact force.

4. Conclusion

In conclusion, the usage of ozone water in cleaning kitchen utensils has shown significant difference compared to using the traditional way of cleaning with the aid of a nozzle. The nozzle prototype has given the cleaning process a huge boost with a big increment of RLU reduction. The kitchen utensil is tested to be 99% clean after using ozone with the same amount of water and dishwashing liquid as to the traditional way of cleaning. The controlled research has definitely reduced the volume of water used and proven to be much more efficient in cleaning. In terms of manpower, there is no reduction because the time of cleaning is almost the same. The nozzle could help to ease the cleaning of stubborn dirt however, the time of cleaning is almost the same with and without nozzle. Ozone level in the water is also based on the pressure of water, as the backpressure is high, the ozone level dissolved in the water is lesser.

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APPENDIX

Abundance of bacterial taxa in environmental swabs from the hospital cooking center in sampling 1. Only OTUs with >0.1% abundance in more than 20% of the samples are represented.

Taxon	S_BlastChiller_Wall	S_ColdStorage_Shelf	S_ColdStorage_Wall	K_Balance	K_Sink	K_Workbench	PPF_Sink	PPF_Workbench	PPR_Cutter	PPR_Sink	PPR_Workbench	PPV_CuttingBoard
<i>Acinetobacter</i>	0.003	0.007	0.001	0.004	0.009	0.001	0.000	0.012	0.001	0.017	0.001	0.000
<i>Acinetobacter johnsonii</i>	0.004	0.071	0.007	0.005	0.096	0.001	0.001	0.009	0.001	0.079	0.001	0.000
<i>Allicyclobacillus</i>	0.266	0.029	0.127	0.000	0.020	0.041	0.030	0.107	0.000	0.021	0.049	0.001
<i>Caulobacter</i>	0.001	0.002	0.001	0.000	0.001	0.000	0.002	0.008	0.000	0.001	0.000	0.046
<i>Chryseobacterium</i>	0.000	0.002	0.000	0.001	0.030	0.000	0.000	0.010	0.000	0.014	0.000	0.003
<i>Corynebacterium</i>	0.003	0.001	0.007	0.000	0.009	0.000	0.002	0.000	0.000	0.002	0.000	0.001
<i>Enterococcus lactis</i>	0.000	0.006	0.002	0.001	0.017	0.000	0.000	0.000	0.022	0.040	0.000	0.000
<i>Kocuria</i>	0.011	0.058	0.042	0.000	0.024	0.001	0.116	0.040	0.000	0.070	0.031	0.006
<i>Kocuria marina</i>	0.000	0.002	0.000	0.000	0.000	0.000	0.002	0.002	0.000	0.001	0.002	0.000
<i>Kocuria palustris</i>	0.006	0.010	0.006	0.000	0.012	0.000	0.006	0.000	0.000	0.028	0.002	0.000
<i>Lactobacillus</i>	0.004	0.000	0.007	0.000	0.002	0.001	0.015	0.004	0.000	0.001	0.000	0.000
<i>Massilia timonae</i>	0.004	0.003	0.001	0.000	0.007	0.000	0.100	0.004	0.000	0.000	0.000	0.091
<i>Moraxellaceae</i>	0.000	0.002	0.000	0.000	0.005	0.000	0.006	0.003	0.000	0.002	0.000	0.000
<i>Paracoccus</i>	0.017	0.007	0.000	0.000	0.018	0.000	0.084	0.004	0.003	0.003	0.001	0.104
<i>Propionibacterium</i>	0.025	0.004	0.009	0.000	0.001	0.006	0.004	0.015	0.000	0.001	0.002	0.000
<i>Pseudomonas</i>	0.028	0.024	0.011	0.241	0.258	0.273	0.001	0.002	0.426	0.010	0.603	0.001
<i>Psychrobacter</i>	0.110	0.190	0.005	0.316	0.023	0.236	0.093	0.001	0.110	0.192	0.000	0.000
<i>Ralstonia</i>	0.000	0.006	0.000	0.000	0.001	0.004	0.003	0.007	0.001	0.001	0.001	0.000
<i>Serratia</i>	0.007	0.000	0.019	0.000	0.001	0.002	0.002	0.004	0.000	0.003	0.001	0.000
<i>Sphingomonas</i>	0.006	0.001	0.006	0.000	0.002	0.000	0.015	0.000	0.000	0.001	0.001	0.057
<i>Staphylococcus</i>	0.005	0.008	0.003	0.000	0.007	0.002	0.002	0.000	0.000	0.004	0.000	0.000
<i>Streptococcus</i>	0.002	0.012	0.000	0.002	0.001	0.013	0.004	0.013	0.000	0.002	0.000	0.000
<i>Streptococcus sanguinis</i>	0.051	0.018	0.140	0.000	0.030	0.011	0.018	0.035	0.006	0.070	0.007	0.001
<i>Streptococcus thermophilus</i>	0.005	0.002	0.005	0.000	0.003	0.002	0.002	0.004	0.001	0.004	0.000	0.000
Other	0.018	0.047	0.022	0.011	0.023	0.016	0.023	0.046	0.010	0.014	0.009	0.016

PPV_Grinder	PPV_Sink	PPV_Workbench	PPW_Sink	PPW_Workbench	T_Colander	T_CuttingBoard	T_Knife	T_Pan	T_SteelDish	T_SteelPincers	T_SteelShovel	T_SteelTray
0.015	0.082	0.010	0.001	0.018	0.007	0.001	0.000	0.001	0.000	0.003	0.392	0.001
0.001	0.031	0.033	0.033	0.100	0.793	0.000	0.001	0.012	0.001	0.004	0.004	0.003
0.001	0.000	0.166	0.092	0.210	0.036	0.000	0.005	0.313	0.002	0.121	0.020	0.058
0.001	0.022	0.002	0.005	0.006	0.000	0.000	0.000	0.004	0.000	0.001	0.001	0.003
0.017	0.029	0.005	0.006	0.027	0.005	0.007	0.000	0.000	0.002	0.001	0.000	0.000
0.009	0.000	0.002	0.010	0.002	0.001	0.003	0.005	0.002	0.000	0.001	0.001	0.003
0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.002	0.001	0.000	0.018	0.007	0.000
0.076	0.000	0.008	0.046	0.000	0.000	0.019	0.322	0.002	0.014	0.010	0.001	0.002
0.002	0.000	0.000	0.001	0.002	0.001	0.001	0.005	0.000	0.000	0.001	0.000	0.000
0.198	0.000	0.001	0.022	0.005	0.000	0.000	0.005	0.000	0.002	0.001	0.000	0.001
0.000	0.000	0.011	0.033	0.004	0.001	0.002	0.001	0.023	0.000	0.003	0.001	0.007
0.049	0.137	0.002	0.061	0.006	0.001	0.000	0.000	0.000	0.000	0.001	0.001	0.000
0.001	0.002	0.043	0.017	0.001	0.101	0.001	0.024	0.000	0.000	0.004	0.001	0.004
0.023	0.088	0.009	0.004	0.013	0.000	0.000	0.000	0.002	0.079	0.001	0.012	0.002
0.010	0.000	0.034	0.004	0.008	0.003	0.000	0.000	0.016	0.000	0.010	0.003	0.034
0.001	0.040	0.038	0.007	0.007	0.019	0.092	0.029	0.006	0.000	0.003	0.004	0.002
0.094	0.000	0.008	0.000	0.001	0.004	0.276	0.0015	0.488	0.006	0.001	0.001	0.002
0.000	0.000	0.008	0.001	0.009	0.000	0.000	0.000	0.011	0.000	0.007	0.001	0.032
0.000	0.000	0.016	0.001	0.007	0.001	0.000	0.000	0.043	0.000	0.006	0.000	0.003
0.000	0.026	0.003	0.007	0.005	0.001	0.000	0.000	0.004	0.033	0.000	0.001	0.001
0.000	0.010	0.004	0.004	0.001	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000
0.000	0.000	0.015	0.005	0.003	0.002	0.000	0.000	0.011	0.000	0.028	0.002	0.032
0.001	0.000	0.088	0.026	0.058	0.032	0.100	0.017	0.267	0.001	0.052	0.032	0.076
0.000	0.000	0.008	0.003	0.005	0.001	0.003	0.000	0.013	0.000	0.007	0.005	0.006
0.031	0.019	0.028	0.025	0.020	0.011	0.014	0.014	0.006	0.049	0.030	0.012	0.017

Appendix 1: Bacteria count in hospital food service sample 1.

Abundance of bacterial taxa in environmental swabs from the hospital cooking center in sampling 2. Only OTUs with >0.1% abundance in more than 20% of the samples are represented.

Taxon	S_BlastChiller_Wall	S_ColdStorage_Shelf	S_ColdStorage_Wall	K_Balance	K_Sink	K_Workbench	PPF_Sink	PPF_Workbench	PPR_Cutter	PPR_Sink	PPR_Workbench	PPV_CuttingBoard
<i>Acinetobacter</i>	0.000	0.000	0.007	0.000	0.056	0.005	0.017	0.032	0.031	0.006	0.159	0.133
<i>Acinetobacter johnsonii</i>	0.001	0.001	0.001	0.000	0.032	0.002	0.005	0.014	0.020	0.023	0.319	0.056
<i>Allicyclobacillus</i>	0.001	0.004	0.067	0.000	0.002	0.076	0.000	0.015	0.000	0.005	0.001	0.000
<i>Brochothrix</i>	0.002	0.285	0.013	0.024	0.000	0.005	0.000	0.003	0.004	0.030	0.000	0.000
<i>Caulobacteraceae</i>	0.000	0.000	0.001	0.000	0.007	0.004	0.000	0.002	0.000	0.039	0.001	0.000
<i>Chryseobacterium</i>	0.000	0.000	0.000	0.000	0.053	0.000	0.036	0.034	0.002	0.039	0.020	0.000
<i>Corynebacterium</i>	0.000	0.001	0.012	0.000	0.000	0.016	0.000	0.001	0.023	0.000	0.007	0.000
<i>Kocuria</i>	0.009	0.002	0.158	0.000	0.004	0.015	0.488	0.006	0.068	0.230	0.003	0.000
<i>Kocuria palustris</i>	0.001	0.001	0.051	0.000	0.023	0.004	0.012	0.000	0.007	0.056	0.000	0.000
<i>Massilia timonae</i>	0.001	0.000	0.002	0.000	0.008	0.033	0.061	0.032	0.001	0.097	0.008	0.009
<i>Microbacterium</i>	0.000	0.000	0.000	0.000	0.005	0.001	0.000	0.029	0.000	0.001	0.001	0.000
<i>Moraxellaceae</i>	0.000	0.000	0.003	0.000	0.036	0.007	0.001	0.000	0.035	0.039	0.081	0.009
<i>Paracoccus</i>	0.000	0.000	0.057	0.000	0.007	0.042	0.042	0.209	0.018	0.054	0.023	0.000
<i>Propionibacterium</i>	0.003	0.003	0.046	0.000	0.001	0.033	0.000	0.008	0.000	0.001	0.000	0.000
<i>Pseudomonas</i>	0.794	0.020	0.020	0.951	0.005	0.005	0.038	0.006	0.012	0.016	0.002	0.022
<i>Psychrobacter</i>	0.000	0.069	0.004	0.000	0.161	0.145	0.041	0.026	0.224	0.028	0.003	0.002
<i>Rhodobacteraceae</i>	0.000	0.000	0.006	0.000	0.002	0.000	0.000	0.015	0.000	0.016	0.023	0.001
<i>Sphingobacterium faecium</i>	0.000	0.000	0.000	0.000	0.008	0.000	0.058	0.037	0.002	0.000	0.000	0.000
<i>Sphingomonas</i>	0.003	0.000	0.000	0.000	0.001	0.000	0.001	0.056	0.000	0.004	0.001	0.000
<i>Stenotrophomonas</i>	0.000	0.000	0.000	0.000	0.002	0.000	0.020	0.009	0.006	0.004	0.003	0.000
Other	0.035	0.007	0.048	0.005	0.044	0.028	0.026	0.023	0.040	0.034	0.035	0.015

PPV_Grinder	PPV_Sink	PPV_Workbench	PPW_Sink	PPW_Workbench	T_Colander	T_CuttingBoard	T_Knife	T_Pan	T_SteelDish	T_SteelPincers	T_SteelShovel	T_SteelTray
0.000	0.011	0.031	0.045	0.031	0.051	0.003	0.017	0.001	0.087	0.003	0.044	0.004
0.000	0.074	0.100	0.011	0.407	0.516	0.001	0.001	0.007	0.535	0.009	0.545	0.058
0.008	0.000	0.000	0.000	0.001	0.072	0.000	0.000	0.015	0.004	0.091	0.008	0.006
0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.004
0.000	0.016	0.021	0.026	0.000	0.003	0.010	0.000	0.001	0.000	0.000	0.000	0.000
0.002	0.007	0.094	0.083	0.002	0.003	0.303	0.081	0.000	0.163	0.001	0.002	0.003
0.001	0.000	0.001	0.002	0.010	0.000	0.008	0.001	0.001	0.000	0.028	0.002	0.001
0.042	0.018	0.031	0.032	0.013	0.001	0.048	0.008	0.010	0.002	0.070	0.001	0.012
0.007	0.002	0.042	0.009	0.000	0.000	0.001	0.001	0.002	0.000	0.006	0.000	0.000
0.000	0.003	0.018	0.025	0.022	0.003	0.025	0.299	0.000	0.000	0.003	0.001	0.010
0.001	0.042	0.001	0.020	0.001	0.001	0.003	0.000	0.000	0.000	0.002	0.000	0.000
0.000	0.017	0.001	0.045	0.015	0.011	0.003	0.001	0.005	0.002	0.011	0.000	0.000
0.008	0.086	0.098	0.048	0.000	0.003	0.001	0.050	0.008	0.000	0.007	0.001	0.000
0.001	0.000	0.000	0.000	0.001	0.004	0.000	0	0	0	0	0	0
0.001	0.221	0.104	0.036	0.007	0.117	0.004	0.024	0.004	0.072	0.010	0.002	0.001
0.000	0.002	0.001	0.150	0.002	0.009	0.073	0.190	0.205	0.001	0.014	0.006	0.391
0.013	0.039	0.003	0.002	0.000	0.001	0.000	0.001	0.001	0.000	0.002	0.001	0.000
0.000	0.000	0.000	0.019	0.000	0.001	0.080	0.000	0.000	0.000	0.000	0.001	0.000
0.002	0.020	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000
0.001	0.010	0.050	0.010	0.001	0.001	0.045	0.004	0.000	0.000	0.000	0.001	0.000
0.187	0.047	0.027	0.037	0.013	0.037	0.037	0.034	0.044	0.011	0.133	0.047	0.001



Appendix 3: Focus point of the water spray used in Taylor’s School of Hospitality and Culinary Arts kitchen.



Appendix 4: Water spray profile.